

# Technology Assessments: Hybrid, Battery Electric, and Fuel Cell Electric Vehicles

November 19, 2015

**California Environmental Protection Agency**

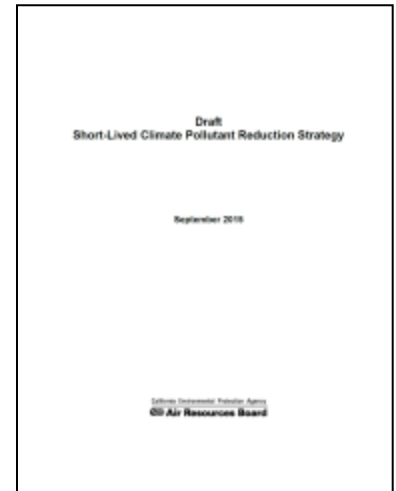
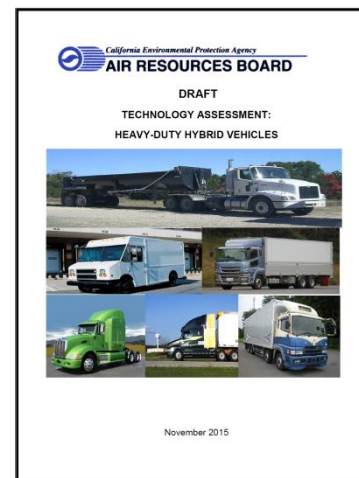
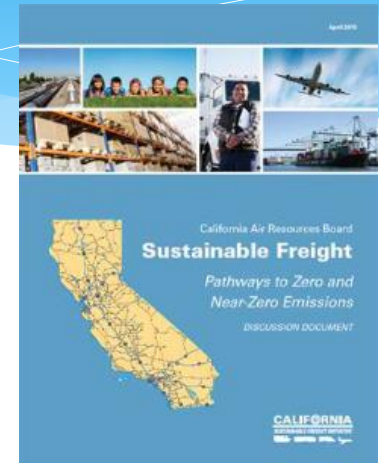
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**Air Resources Board**



# Multiple Near- and Long-Term Planning Efforts Underway

- \* Mobile Source Strategy framework supports multiple planning efforts
  - \* SIP
  - \* Scoping Plan
  - \* Sustainable Freight
- \* Hybrid, BEV, and FCEV Technology Assessments
  - \* 5 – 10 year outlook
  - \* For medium- and heavy-duty vehicles (8,500 lbs.+)
  - \* Provide technical foundation



# Clear Need for Diverse Portfolio of Technologies

- \* Portfolio of zero- and near-zero technologies
  - \* Clean Combustion/Low-NOx
  - \* Hybrids
  - \* Fuel Cells
  - \* Battery Electric
- \* Renewable fuels needed for deep GHG reductions
  - \* Natural gas
  - \* Diesel/gasoline
  - \* Electricity
  - \* Hydrogen

# Technology Assessments Support On-going Planning Efforts

- \* Inform technical foundation for future regulatory efforts
  - \* Potential new regulatory efforts
  - \* Development of renewable fuels
  - \* Support infrastructure investments
  - \* Demonstration and deployment of advanced technologies
- \* Investing in advanced technologies
  - \* Low carbon transportation
  - \* Air Quality Improvement Program
  - \* Alternative and Renewable Fuel and Vehicle Technology Program

# Technology Assessments Have Been Underway since Early 2014

Early 2014

- Technology assessments begun

Dec. 2014

- Board briefing status update

April 2015

- Overview report

June 2015

- Vehicle and Drivetrain Efficiency

July 2015

- TRU and Commercial Harbor Craft

Sept. 2015

- Low NOx Diesel and Natural Gas

Oct. 2015

- Battery Electric Trucks and Buses

Nov. 2015

- Cargo Handling, Hybrid, and Fuel Cell Electric Vehicle

# Key Findings Provide a Path to 2030 and Beyond

- \* Near-term focus on clean combustion coupled with renewable fuel
  - \* Maximizes NOx reductions needed for air quality attainment
  - \* Use of renewable fuels ensure progress towards 2030 goals
  - \* Zero emission vehicle deployments necessary
    - \* Continued technology commercialization
    - \* Additional localized risk reductions
- \* Longer-term support for growing zero-emission technology
  - \* Growing deployment of electric propulsion vehicles
  - \* Clean combustion still needed
  - \* Growing need for renewable fuels

# Diesel and Natural Gas Assessments



# Lower NOx Achievable for Both Diesel and Natural Gas Engines

- \* Diesel:

- \* Reducing emissions during cold start and low-temperature, low-speed city driving
- \* Maintaining high SCR efficiency at other times

- \* Natural Gas:

- \* Systems approach combining advanced three-way catalysts with engine management strategies
- \* 8.9 liter engine recently certified as 90% cleaner

- \* ARB-funded SwRI Low NOx Work

- \* Target: 0.02 g/bhp-hr NOx for diesel and natural gas with minimal GHG impact



# Clean Combustion Important for Near- and Long-Term Reductions

- \* Low-NO<sub>x</sub> natural gas engines likely to be available sooner than for diesel
  - \* Both are critical for attainment of air quality standards
- \* Well-to-wheel GHG emissions need to be addressed
  - \* Higher than for fuel cell and battery electric
- \* Renewable fuels provide potential solution
  - \* Available quantities could be limiting factor
- \* Complementary advanced technologies will needed

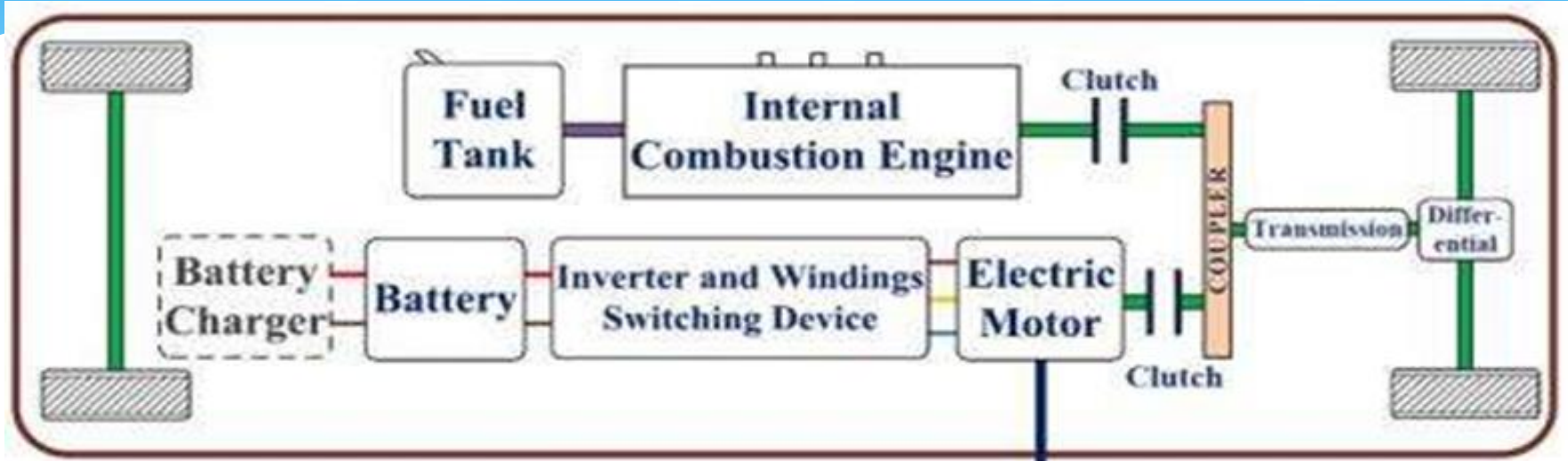
# Advanced Clean Transit Concept: Near-Zero and Zero Emission Technologies

- \* Transit fleets - an ideal early application of electric and fuel cell technology
- \* Mix of cleaner combustion & zero-emission buses
  - \* Low NOx technologies
  - \* Use of renewable fuels
  - \* Phased-in adoption of zero-emission technologies
  - \* Natural fleet replacement rate (not accelerated)
- \* Increased engagement with stakeholders a priority
  - \* Establish transit workgroup
  - \* Conduct technology and regulatory workshops
  - \* Evaluate economics and business case, funding and incentives
- \* Update Board early 2016

# Hybrid Vehicles



# What is a Hybrid Vehicle?



Degree of hybridization:

Micro  
hybrid

Mild  
hybrid

Full hybrid

Plug-in  
hybrid

# Hybrids Currently Best Suited for Urban Driving Cycles

- \* High kinetic intensity: Heavy urban start-and-stop, aggressive acceleration/deceleration events, high idle time
  - Examples: Refuse haulers, transit buses, package/delivery trucks
- \* Utilize electric power take-off (ePTO)
  - Examples: Utility and tree trimming services

# >2,500 Medium-/Heavy-duty Hybrids On Road in CA

Vehicle Type	Technology Readiness	Number in Service in CA
Parcel Delivery	Commercially available	830
Uniform & Linen Delivery		110
Beverage Delivery		440
Food Distribution & Other Trucks		680
Buses (Transit, Shuttle, School)		470
Other		Demos: Utility/Bucket Trucks, Drayage

- Many more in use overseas, most in China, South America, Europe, India

# Expanding Hybrids into Additional Applications

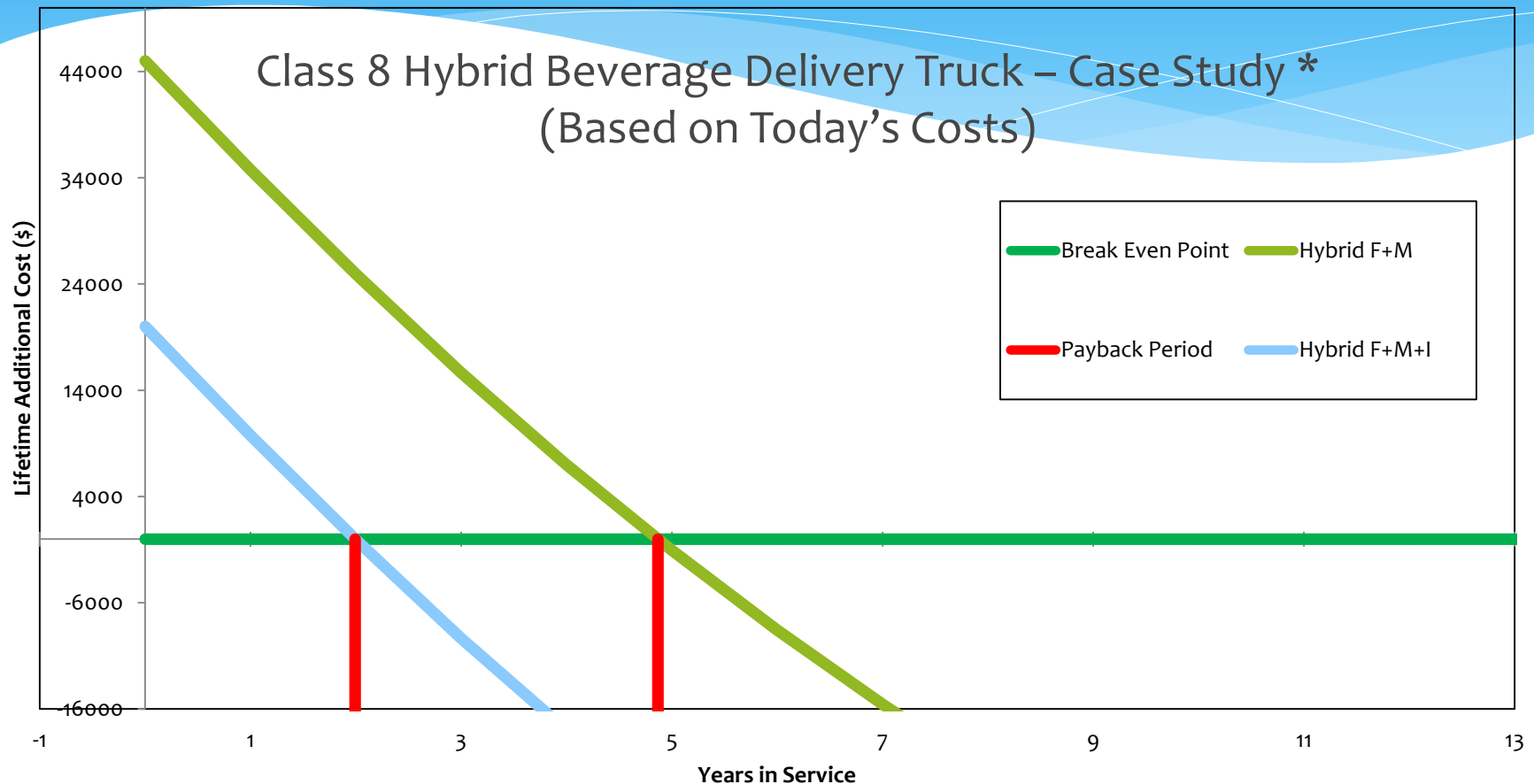
- \* Class 3-8 rural/intracity and regional delivery, and drayage
- \* Plug-in hybrids for utility/bucket truck applications, with increased use of ePTO, plug-in drayage
- \* Line haul trucks may adopt mild hybridization as efficiency standards tighten

# Overcoming Market Challenges

- \* **Cost: ~20% to 50% of vehicle purchase cost**
  - Costs relatively high at low volume
  - Solutions: O&M savings, incentives, increasing volumes
- \* **Performance: High-power demand applications**
  - Solutions: Battery improvements, system optimization
- \* **Weight: Weight penalty of 300 lbs.-4,500 lbs.**
  - Solutions: Light weighting, route selection
- \* **Certification: OBD and NOx emissions challenges**
  - Solutions: Innovative Technologies Regulation, improve engineering designs and system integration



# Hybrid Technologies Can provide Overall Cost Savings to Fleets



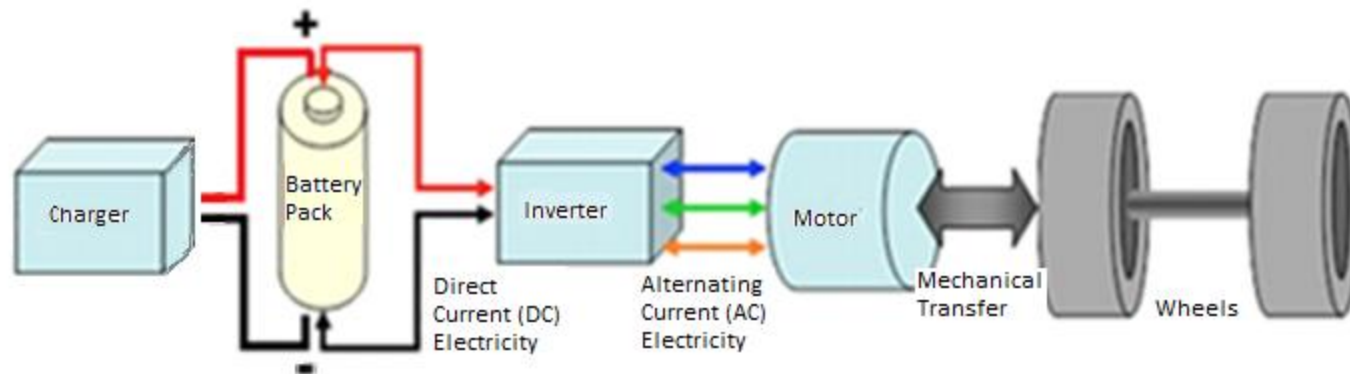
"F" = Fuel savings, "M" = Maintenance Savings "I" = Incentives

\* NREL "Coca-Cola Refreshments Class 8 Diesel Electric Hybrid Tractor Evaluation: 13-Month Final Report" - NREL/TP-5400-53502 August 2012- K. Walkowicz, M. Lammert, and P. Curran

# Battery-Electric Vehicles (BEVs)



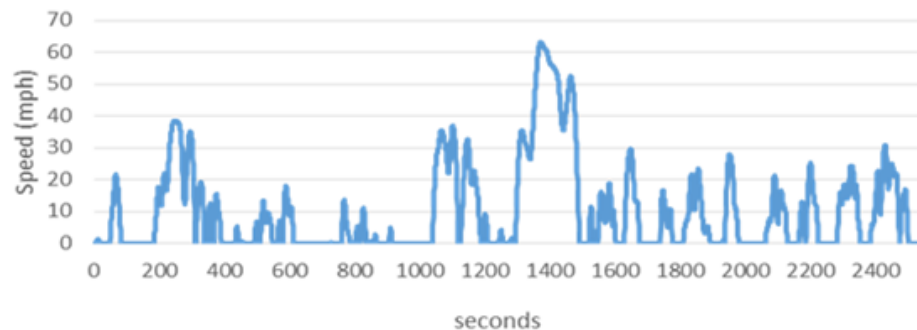
# What is a Battery-Electric Vehicle?



- \* A vehicle using batteries as the sole source of power
- \* Components:
  - Electric motor
  - Battery pack and battery management system

# Optimal BEV Duty Cycle is Similar to Hybrid's

- \* Urban or suburban routes
- \* Frequent start and stop
- \* High idle times/lower average speeds
- \* Daily ranges of 100 miles or less
- \* This makes them particularly suitable in early years for:
  - Transit buses
  - Shuttle buses
  - Delivery trucks



# Hundreds of Medium-/Heavy-Duty BEVs in California

Vehicle Type	Technology Readiness	Number in Service
Transit Bus	Commercially Available	~40 in California, >2,500 worldwide
School Bus	Limited Commercial	4 in California
Medium-Duty	Limited Commercial	300+
Heavy-Duty (> 14,000 lbs. GVWR )	Demonstration	2 Drayage 1 Refuse

# Overcoming Market Challenges

- \* Range

- Solutions: Battery improvements, fast-charge technology

- \* Incremental cost (Bus: ~ 50% of purchase cost)

- Solutions: O&M savings, incentives, increasing volumes

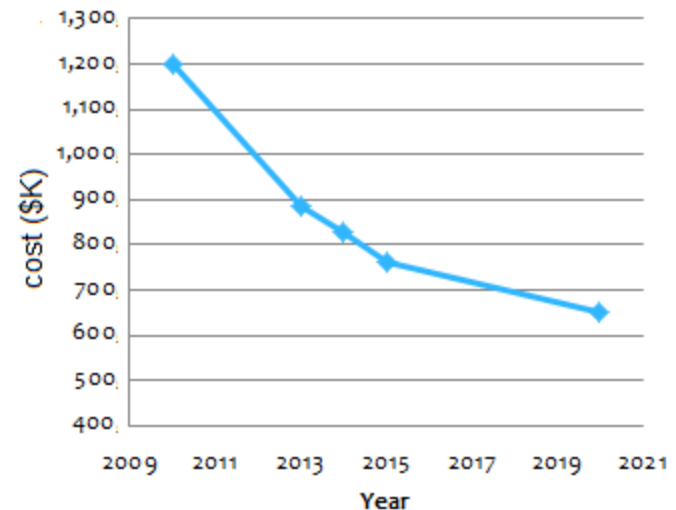
- \* Weight

- Solutions: Battery improvements, light weighting

- \* Charging/infrastructure

- Solution: Incentives

**Battery Electric Transit Bus  
Cost vs. Time**



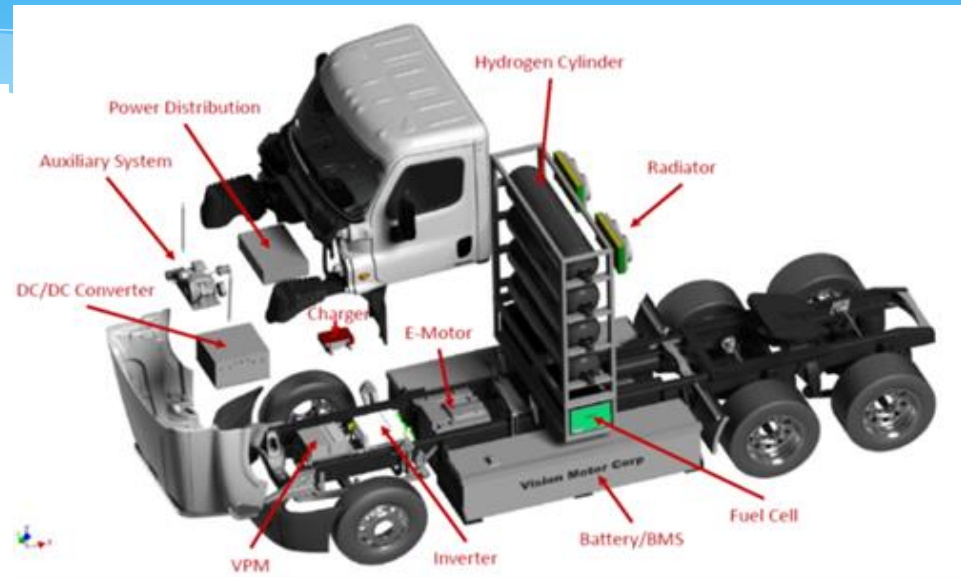
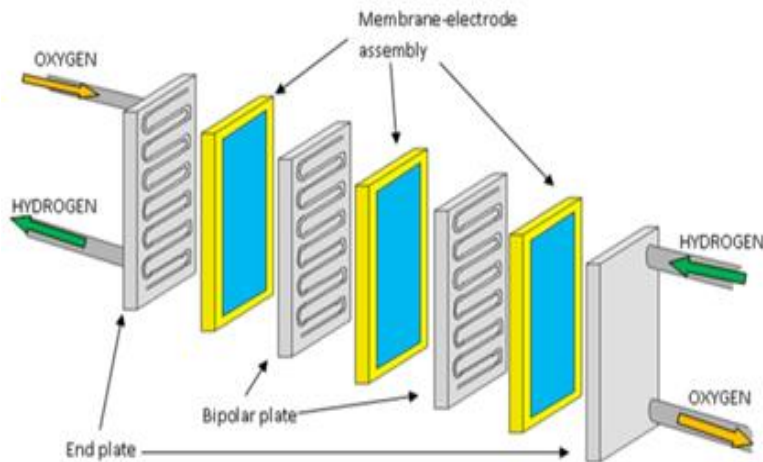


# Fuel Cell Electric Vehicles (FCEVs)



# What is a FCEV?

Fuel cell stack



- \* Fuel cell system generates electricity to propel the vehicle and operate auxiliary equipment
- \* Components: Fuel cell stack, drivetrain, energy storage system, hydrogen storage system, cooling systems, and DC/DC converter(s)



# Dozens of Medium-/Heavy-Duty FCEVs On Road

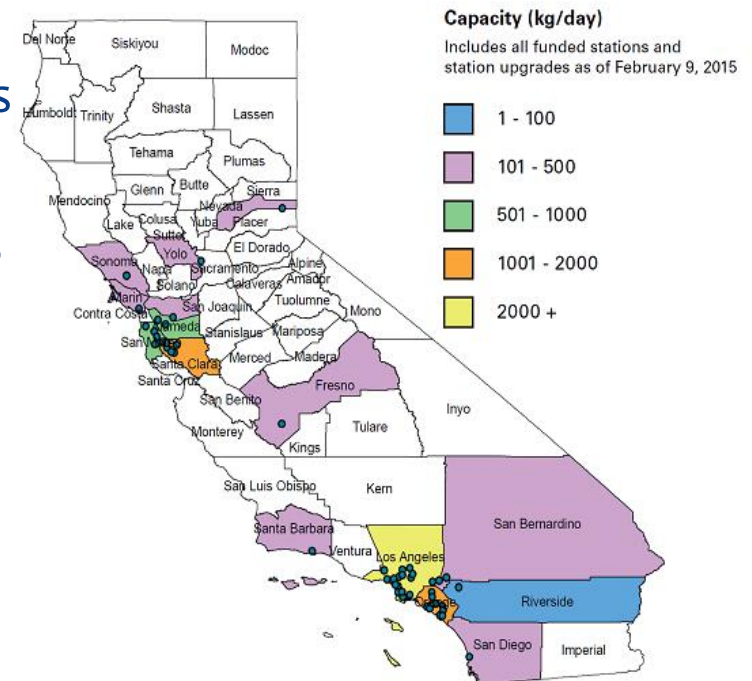
Vehicle Type	Technology Readiness	Active/Planned Demonstrations
Transit Bus	Limited Commercial	23 active/22 planned
Shuttle Bus	Demonstration	2 active/8 planned
Delivery Vehicles	Demonstration	38 active/planned
Drayage Trucks	Demonstration	12 active/planned

# Overcoming Market Challenges

- \* Fuel Cells solve the battery range issue and have good reliability but:
  - Training maintenance staff
    - Solution: training program improvements
  - Currently slightly lower availability than diesel
    - Solutions: parts availability, training programs
  - Incremental cost still high: >100% of purchase cost
    - Solutions: increasing volumes, learning curve
  - Fueling infrastructure
    - Solutions: incentives, demand

# Supporting Fueling Infrastructure Must be a Priority

- \* Extensive work done to plan light-duty hydrogen fueling infrastructure
  - \* Data gathering from manufacturers
  - \* ARB analytical tools project station gaps
  - \* \$20 million annually in CEC funding
  - \* Network of 51 stations expected by 2016
- \* Medium-/heavy-duty fueling at different pressure
- \* Need similar effort for medium-/heavy-duty fueling



# Clean Advanced Technologies Are Key to Meeting Future Goals

# Advanced Technologies Will Provide Critical Emission Benefits

- \* Hybrids:

- Potential NOx benefits
- Modest GHG benefits

- \* BEVs :

- Zero tailpipe emissions
- Well-to-wheel and lifecycle GHG emission benefits

- \* FCEVs:

- Zero tailpipe emissions
- Well-to-wheel and lifecycle GHG emission benefits

# Payback Periods Improving with Decreasing Incremental Costs

- \* Hybrids:
  - Reduced O&M costs
  - Payback period varies from 3 to 18 years
- \* BEVs:
  - Reduced O&M
  - Payback in 4+ years
- \* FCEVs:
  - Payback assessment still under development

# Comprehensive Strategies to Expand Use of Advanced Technologies

- \* Planning efforts highlight need for diverse technology portfolio
  - \* Clean combustion
  - \* Zero-emission
  - \* Renewable fuels
- \* Public investments are supporting technology development
  - \* Incentives are prioritizing both clean combustion and zero-emission
  - \* Multiple applications targeted
- \* Regulatory development underway

# Measures Under Development to Encourage Advanced Technologies

- \* Innovative Technologies – 2016
- \* Advanced Clean Transit – 2016
- \* Heavy-Duty GHG Phase 2 – 2016-2017
- \* Last Mile Delivery – 2017
- \* Zero Emission Airport Shuttle Buses – 2017-2018



# Moving Forward

- \* Staff will continue to work with stakeholders on ARB planning and measure development
  - \* Near- and long-term scenarios
  - \* Both clean combustion and zero-emission
- \* Technology assessments posted as drafts
  - \* Accepting comments
  - \* Will support ARB planning and regulatory efforts
- \* Advanced technology trucks are here
  - \* Commercially available and/or in demonstration
- \* Challenges exist, but so do solutions